Introduction to OpenSees and Tcl

Frank McKenna

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What is OpenSees?

The Open System for Earthquake Engineering Simulation is:

• A software *framework* for developing sequential, parallel and grid-enabled simulation applications in earthquake engineering using finite element methods.
What is a Software Framework?

• A *framework* is a set of cooperating software components for building applications in a specific domain.

• A framework dictates the architecture of the application. It must represent the design decisions common to the application domain.

• A frameworks is based on the assumption that an architecture will work for most applications within the domain.

• Loose-coupling of components within the framework is essential for extensibility and re-useability for applications.

• *A framework is not a “code”; it is not a .exe*
Conceptual Approach for Simulation

Open-Source Community Simulation Framework

Computation

Information Technology

Software framework, Databases, Visualization, Internet/grid computation

Models

Simulation models, Performance models, Limit state models

Material, component, system models

Algorithms, Solvers, Parallel/distributed computing
Main Abstractions in OpenSees

- **ModelBuilder**: Constructs the objects in the model and adds them to the domain.
- **Domain**: Holds the state of the model at time $t$ and $(t + dt)$
- **Recorder**: Monitors user defined parameters in the model during the analysis.
- **Analysis**: Moves the model from state at time $t$ to state at time $t + dt$.
What Types of Recorder

Recorder

Element
Node
EnvelopeNode
EnvelopeElement
Database
FilePlotter
Display

Renderer

DataOutputHandler

StreamHandler
FileHandler
DatabaseHandler

Database

X11
OpenGL
VRML

File
MySQL
Oracle
NEES
What is in a Domain

- **Element**
  - Truss
  - ZeroLength
  - ElasticBeamColumn
  - NonlinearBeamColumn (force, displacement)
  - BeamWithHinges
  - Quad (std, bbar, enhanced, u-p)
  - Shell
  - Brick (std, bbar, 20node, u-p, u-p-U)
  - Joint
  - *ExperimentalElement*

- **Node**

- **MP_Constraint**

- **SP_Constraint**

- **LoadPattern**

- **TimeSeries**
  - Constant
  - Linear
  - Rectangular
  - Sine
  - Path

- **ElementalLoad**

- **NodalLoad**

- **SP_Constraint**
Some Other Classes associated with Elements:

- GeomTransformation
- Linear
- Pdelta
- Corotational

Element in Global System

Geometric Transformation

Element in Basic System
Other Classes associated with Elements:

- **Material**
  - **Uniaxial**
    - Elastic
    - ElasticPP
    - Hardening
    - Concrete
    - Steel
    - Hysteretic
    - PY-TZ-QZ
    - Parallel
    - Series
    - Gap
    - Fatigue
  - **nD**
    - Elastic
    - J2
    - TemplateElasto-Plasto
    - FluidSolidPorous
  - **Section**
    - Elastic
    - Fiber
    - PressureMultiYield (dependent, independent)
What is an Analysis

- **Analysis**
  - StaticAnalysis
  - TransientAnalysis

- **CHandler**
  - Penalty
  - Lagrange Transformation
  - RCM
  - MinDegree

- **Numberer**
  - EquiSolnAlgo
    - Linear
    - NewtonRaphson
    - ModifiedNewton
    - Broyden
    - BFGS
    - KrylovNewton
    - NewtonLineSearch

- **AnalysisModel**
  - StaticIntegrator
    - LoadControl
    - DispControl
    - ArcLength
    - MinUnbalDispNorm

- **SolnAlgorithm**
  - TransientIntegrator
    - Newmark
    - HHT
    - CentralDifference

- **Integrator**
  - BandGeneral
  - BandSPD
  - ProfileSPD
  - SparseGeneral
  - SparseSymmetric

- **SystemOfEqn**
  - Linear
  - Linear
  - Linear

- **CTest**
Classes for Parallel & Distributed Processing

- **Channel** objects for communicating between processes
- **ObjectBroker** for creating blank objects upon which recvSelf() called
- **Shadow** (Proxy) objects to hide parallelism from existing objects
- **Actor** objects to sit on a remote process & process task requested
- **Machine** objects to start/manage processes (returns Channel to Shadow objects)
OpenSees.exe

- OpenSees is an Open-Source Software Framework for developing Nonlinear Finite Element Applications for both sequential and parallel environments.

- OpenSees.exe is an extension of the Tcl interpreter for finite element analysis which uses this framework. It is an example of an application that can be developed using the framework.
What is Tcl

- Tcl is a string based scripting language.
- Variables and variable substitution
- Expression evaluation
- Basic control structures (if, while, for, foreach)
- Procedures
- File manipulation
- Sourcing other files.
Tcl

- Tcl scripts are made up of commands separated by newlines or ;
- Command syntax:
  
  \texttt{command arg1 arg2 \ldots}

- Help
  
  
  2. Practical Programming in Tcl and Tk, Brent B. Welch, Prentice Hall.
Example Tcl:

```tcl
for {set i 1} {$i < 10} {incr i 1} {
    puts “i equals $i”
}
set sum 0
foreach value {1 2 3 4} {
    set sum [expr $sum + $value]
}
set $sum
>10
>proc guess {value} {
    global sum
    if {$value < $sum} {
        puts “too low”
    } else {
        if {$value > $sum} {
            puts “too high”
        } else { puts “you got it!”}
    }
}
> guess 9
too low

>proc sum {a b} {
    return [expr $a + $b]
}
>sum 2 3
>5
>set c [sum 2 3]
>5

>set fileId [open tmp w]
>??
>puts $fileId “hello”
>close $fileId
>type tmp
hello
>
```

```tcl
>source Example1.tcl

>set a 1
>1
>set b $a
>a
>set fileId [open tmp w]
>??
>set fileId [open tmp w]
>expr 2 + $a
>5
>expr 2 + $a
>3
>set b [expr 2 + $a]
>3
>set b a
>1
>set b $a
>a
>expr 2 + 3
>5
>expr 2 + 3
>5

>set c [expr 2 + $a]
>3
>set c [expr 2 + $a]
>3
```

```tcl
>source Example1.tcl

>set fileId [open tmp w]
>type tmp
hello
```
Commands to Tcl for OpenSees

For OpenSees we have added commands to Tcl for finite element analysis:
1. Modeling – create nodes, elements, loads and constraints
2. Analysis – specify the analysis procedure.
3. Output specification – specify what it is you want to monitor during the analysis.
Model Generation:
*Adds the modelling commands to the interpreter.

•BasicBuilder

```
model Basic  –ndm ndm? <-ndf ndf?>
```

This command now adds the following commands to the interpreter:

- node
- element
- pattern
- fix
- equalDOF
- pattern
- load
- eleLoad
- sp
- mass
- fix
- fixX
- fixY
- fixZ
- uniaxialMaterial
- nDMaterial
- section
- geomTransf
- block2D
- block3D
- patch
- layer
- fiber
Analysis

- **CHandler**
  - Penalty
  - Lagrange
  - Transformation

- **Numberer**
  - RCM
  - MinDegree

- **AnalysisModel**

- **SolnAlgorithm**
  - EquiSolnAlgo
    - Linear
    - NewtonRaphson
    - ModifiedNewton
    - BFGS
    - KrylovNewton
  - StaticIntegrator
    - LoadControl
    - DispControl
    - ArcLength
    - MinUnbalDispNorm

- **Integrator**
  - TransientIntegrator
    - Newmark
    - HHT

- **SystemOfEqn**
  - BandGeneral
  - BandSPD
  - ProfileSPD
  - SparseGeneral
  - SparseSymmetric

- **Solver**
  - StaticAnalysis
  - TransientAnalysis

**constraints type? args...**

**numberer type? args...**

**algorithm type? args...**

**integrator type? args...**

**system type? args...**

**analysis type? args...**

**analyze args ...**

---

OpenSees
Example Model:

```
model Basic -ndm -ndf 2
node 1 0.0 0.0
node 2 144.0 0.0
node 3 168.0 0.0
node 4 72.0 96.0
fix 1 1 1
fix 2 1 1
fix 3 1 1
uniaxialMaterial Elastic 1 3000.0
element truss 1 1 4 10.0 1
element truss 2 2 4 5.0 1
element truss 3 3 4 5.0 1
Pattern Plain 1 “Linear” {
    load 4 100.0 -50.0
}
```
Example Analysis:

• **Static Nonlinear Analysis with LoadControl**
  
  constraints transformation
  numberer RCM
  system BandGeneral
  test NormDispIncr 1.0e-6 6 2
  algorithm Newton
  integrator LoadControl 0.1
  analysis Static
  analyze 10

• **Transient Nonlinear Analysis with Newmark**
  
  constraints transformation
  numberer RCM
  system BandGeneral
  test NormDispIncr 1.0e-6 6 2
  algorithm Newton
  integrator Newmark 0.5 0.25
  analysis Transient
  analyze 2000 0.01
And Why do Finite Element Analysis
NCEER frame tested at the Taiwan facility

Centerline model and model with joint comparison
OpenSees Community Website

- Web site: http://opensees.berkeley.edu/
- User Pages
  - Command Manual
  - Examples Manual
  - Browse the Source Code
  - Message Board
  - Bug Reporting!